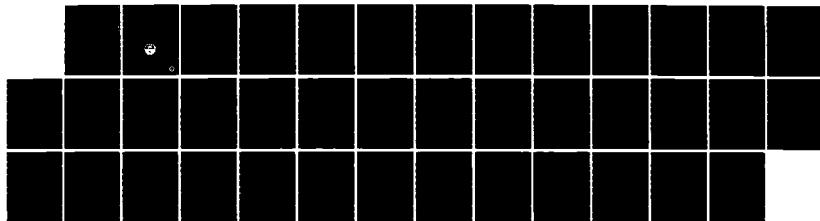
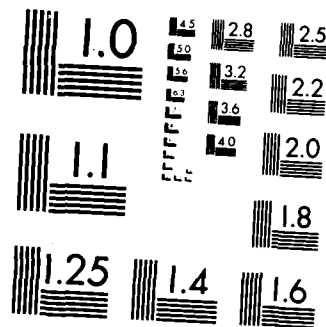


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ENGINEER AND TECH. (U) NAVY PERSONNEL RESEARCH AND  
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OCTOBER 1986

**A MODEL FOR ESTIMATING DIRECT-FUNDED  
CIVILIAN SCIENTIST, ENGINEER, AND TECHNICIAN  
STAFFING IN THE NAVY RESEARCH AND DEVELOPMENT CENTERS**

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**A MODEL FOR ESTIMATING DIRECT-FUNDED CIVILIAN SCIENTIST,  
ENGINEER, AND TECHNICIAN STAFFING IN THE NAVY  
RESEARCH AND DEVELOPMENT CENTERS**

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<p>This report describes the development and implementation of a model that projects scientist, engineer, and technician (SE&amp;T) staffing levels at the Department of Navy Laboratories research and development (R&amp;D) centers by product area, given specific funding levels and in-house/contract mixes. The model can also be used to evaluate the impacts of personnel ceiling and in-house dollar expenditure limits. The results should be of interest to defense R&amp;D managers concerned with matching workload with workforce.</p>			
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## FOREWORD

This project was conducted in response to a Director of Navy Laboratories (DNL) request to develop a manpower estimating model (MEM) to estimate direct-funded scientist, engineer, and technician (SE&T) staffing levels for the eight DNL Research and Development (R&D) centers. This report describes the development and implementation of a model that forecasts SE&T staffing levels at the DNL R&D centers by product area, given specific funding levels and in-house/contract mixes. The model can also be used to evaluate the impacts of personnel ceiling and in-house dollar expenditure limits. The results should be of interest to defense R&D managers concerned with matching workload with workforce and developing staffing controls for direct R&D functions.

Support in model and software development was provided by Mathtech, Inc. of Falls Church, Virginia, under contract N00123-83-D-0520. The contracting officer's technical representative was Mr. Michael R. Shoecraft.

B. E. BACON  
Captain, U.S. Navy  
Commanding Officer

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Technical Director



A-1

## SUMMARY

### Problem

The Navy research and development (R&D) centers employ a large quantity of highly trained and expensive manpower. Historically, the R&D centers have had difficulty in justifying their manpower requirements to higher authority. The nature of R&D is not amenable to traditional work measurement methodology such as engineered time standards, and there have been no methods available to match workload with staffing.

### Objective

The primary objective of this effort was to develop a manpower estimating model (MEM) for total direct-funded scientist, engineer, and technician (SE&T) staffing levels in the eight Director of Navy Laboratories (DNL) R&D centers. The secondary objective was to provide DNL financial managers with a budget and manpower justification tool.

### Approach

In FY84, the feasibility of developing a method to forecast staffing levels for the DNL R&D centers was assessed by reviewing past attempts to solve the problem, visiting the R&D centers, and identifying applicable data. In FY85, direct workyear and funding data were collected from the annual DNL Five Year Plans for FY80 through FY84 and the DNL financial data base, the Project Listing. Multiple regression analysis was then used to develop an MEM that is both statistically sound and intuitively satisfying.

### Results

The MEM selected has two major variables, funding expended in-house and funding expended on contract, and six special product area intercept variables. The MEM mathematically relates aggregate measures of workload in specific program areas to manpower requirements. The resulting model showed for the average product area that every million dollars (in FY80 dollars) expended in-house required 10.57 direct SE&Ts and every million dollars (in FY80 dollars) expended on contract required 0.697 SE&Ts.

The MEM was implemented on an IBM XT microcomputer. The user-friendly design allows the user to change input parameters, such as total funding and percentage of in-house funding, for "what if" analyses. The user can also constrain total workyears and reallocate workyears and in-house/contract mix across product areas.

### Conclusions and Future Plans

The MEM meets the primary objective of forecasting staffing requirements for the eight DNL R&D centers. It satisfies DNL's interim requirement until individual models for each R&D center are developed. Besides changing policy variables and projecting the effects on direct and total workyears by product area, DNL financial managers can also use the system to analyze the impacts of personnel ceiling and in-house dollar expenditure limits.

The same approach can be extended to the Naval Research Laboratory and the Naval Ocean Research and Development Activity. This would provide these activities with manpower estimating models and staffing control coverage in the Navy Manpower Engineering Program and give the Office of the Chief of Naval Research a manpower planning system for its 10 major R&D centers.

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## INTRODUCTION

### Problem

The Navy's research and development (R&D) centers employ a large quantity of technically trained and expensive manpower. Historically, the R&D centers have had difficulty in justifying their manpower requirements to higher authority. This is because the nature of R&D is not amenable to traditional work measurement methods such as engineered time standards, and no methods were available to justify staffing based on workload.<sup>1</sup> A defensible manpower planning system for the R&D centers is needed.

### Objective

The primary objective of this effort was to develop a manpower estimating model (MEM) to project total direct-funded scientist, engineer, and technician (SE&T) staffing levels for eight Director of Navy Laboratories (DNL) R&D centers. The secondary objective was to provide DNL financial managers with a budget and manpower justification tool.

## APPROACH

### Feasibility Study

In 1984, DNL tasked Navy Personnel Research and Development Center (NAVPERSRANDCEN) to study the feasibility of developing a quantitative method to forecast staffing levels for the DNL R&D centers. Tasking required that the method be developed from existing data bases. The feasibility study consisted of (1) a background study to discover past work that might be applicable, (2) visits to all of the R&D centers, and (3) identification of applicable data.

The background study revealed several unsuccessful attempts to project R&D staffing. One method used by the Navy Civil Engineering Laboratory (NCEL) showed promise (see Appendix A). In fact, the NCEL method was used as a point of departure for the present effort.

The eight DNL R&D centers included in the MEM are the David W. Taylor Naval Ship R&D Center, Carderock and Annapolis, Maryland; Navy Surface Weapons Center, Dahlgren, Virginia and White Oak, Maryland; Navy Weapons Center, China Lake, California; Naval Coastal Systems Center, Panama City, Florida; Naval Air Development Center, Warminster, Pennsylvania; Naval Ocean Systems Center, San Diego, California; Navy Personnel R&D Center, San Diego, California; and Naval Undersea Systems Center, Newport, Rhode Island, and New London, Connecticut.<sup>2</sup> All of the R&D centers were visited at the start of the project to explain the objectives to each center's top management and collect information about the similarities and differences of each center's technical work and operating environment.

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<sup>1</sup> Appendix A summarizes previous attempts by the Navy to standardize and validate R&D manpower requirements.

<sup>2</sup> The ninth activity visited was the Navy Training Systems Center (NTSC). Since the majority of NTSC's manpower performs non-R&D tasks, NTSC could not be included in the MEM. Also, as of 1 October 1985, NTSC was transferred to the cognizance of the Naval Air Systems Command.

### Data Sources

The primary data source used to develop the MEM was the annual DNL Five Year Plan. The annual DNL Five Year Plan contains direct workyears and funding for a base year and five out years for the eight DNL R&D centers. Only the base year data were used because they consisted of about three-quarters of actual data and one-quarter of projections. Out year data contained only projections. Base year planning data were available for fiscal years (FY) 1980 through 1984. Each base year contained data for 38 product areas.<sup>3</sup>

The primary data source used to validate the MEM, make manpower projections, and update the MEM, is the DNL financial data base called the Project Listing. The Project Listing is maintained on the UNIVAC 1100 computer at the Naval Undersea Systems Center in New London, Connecticut, and reports funding and workyear information at the project level for each of the eight DNL R&D centers. The Project Listing was available for FY78 through FY84, but product area identification was not included until FY84. The lack of product area detail in previous years did not allow us to use the Project Listing for developing the MEM.

### Regression Analysis

In the analysis of the base year planning data, the significant variables were funding expended in-house, funding expended on contract, and product area. The notion of having variables for funding expended in-house and funding expended on contract is consistent with the NCEL methodology. Additionally, it seems intuitively satisfying that the diverse product areas of the R&D centers require varying degrees of labor intensity.

## **RESULTS**

### Model Development

The basic model formulation was:

$$WYR = a + b(IHD) + c(CTRD)$$

where

WYR = direct workyears;

IHD = funding expended in-house (millions of 1980 dollars); and

CTRD = contracting out funds (millions of 1980 dollars).

When this model was analyzed for residuals,<sup>4</sup> 10 product areas showed large residuals. Through various diagnostic procedures, dummy intercept and interaction variables were investigated for all product areas with large residuals.

---

<sup>3</sup> Product area definitions are provided here in Appendix B are from Chief of Naval Material, Long Range Plan for the Navy R&D Centers and Laboratories FY-1985 to FY-1989 and Beyond (U), October 1984.

<sup>4</sup> Residual analysis was done by using the model to compute direct workyears for each product area, comparing them to actual workyears, and computing the difference or residual.

Six product area intercept variables were selected: Surface Combat Systems Integration, Surface Vehicles, Subsurface Vehicles, Missiles, Navy Strategic Systems, and Major Range Development and Operation. When this new model was analyzed, only Missiles and Surface Vehicles product areas showed large residuals. Plots of residuals for both models are displayed in Appendix C (Figures C-1 and C-2).

The final model that resulted from the above analysis is shown below:

$$WYR = 10.57(IHD) + 0.697(CTRD) + 75(SUR) + 86(SFV) + 73(SSV) + 83(MIS) + 74(NSS) - 187(MRD) + 22$$

where

WYR = product area "direct charged" SE&Ts;  
 IHD = product area in-house expenditures;  
 CTRD = product area contract expenditures (millions of FY80 dollars)  
 SUR = 1 for Surface Combat Systems Integration product area, 0 otherwise;  
 SFV = 1 for Surface Vehicles, 0 otherwise;  
 SSV = 1 for Subsurface Vehicles, 0 otherwise;  
 MIS = 1 for Missiles, 0 otherwise;  
 NSS = 1 for Navy Strategic Systems, 0 otherwise; and  
 MRD = 1 for Major Range Development and Operation, 0 otherwise.

This equation explains 98 percent of the variation in the data (coefficient of determination of .98).

The above equation implies that if in-house funding is increased by one million dollars, an additional 10.57 SE&Ts is required, and if contract funding is increased by one million dollars, an additional 0.697 SE&Ts is required. The 0/1 variables (i.e., product area variables) imply that some product areas are more labor intensive than others.

Two forms of the equation were considered, the ordinary least squares (OLS) form, shown above, and the difference form. The difference form was derived by computing a difference (a "delta") between a base year and the year to be projected and adding it to the actual values for the base year. In this case, the base year is the latest year with known data, FY84. The general model for the difference form is as follows:

$$WYR_p = WYR_b + 10.57(IHD_p - IHD_b) + 0.697(CTRD_p - CTRD_b)$$

where

WYR<sub>p</sub> = direct workyears to be projected;  
 WYR<sub>b</sub> = actual workyears for base year;  
 IHD<sub>p</sub> = in-house expenditures for projected year (millions of FY80 dollars);  
 IHD<sub>b</sub> = in-house expenditures for base year (millions of FY80 dollars);  
 CTRD<sub>p</sub> = contract expenditures for projected year (millions of FY80 dollars);  
 CTRD<sub>b</sub> = contract expenditures for base year (millions of FY80 dollars).

The coefficients were estimated using FY80 through FY83 data. FY84 workyears were then projected using both forms of the equation. A detailed comparison of projection error for each product area is given in Table C-1 of Appendix C. The difference form was more accurate for 28 of 38 or 74 percent of the product areas and 2.67 times more accurate for the total. In addition, the difference form's largest projection error was 16.1 percent, while the OLS form displayed errors of 46.0 percent, 69.7 percent, and 114.2 percent for three product areas. Consequently, the difference form was selected as the MEM.

### Validation

The MEM was validated three ways. First, each year of data used to develop the model was sequentially set aside and the model coefficients were re-estimated using data from the remaining years. The resulting model was used to project workyears for the missing year.

For example, to use FY81 for validation, the data for FY81 were set aside and the model coefficients were re-estimated using FY80, FY82, FY83, and FY84 data. FY81 workyears were estimated using this new model and compared to the workyears reported in the FY81 base year planning data. This process was repeated for FY82, FY83, and FY84. Table 1 summarizes the results. (Detailed results by product area are shown in Table C-2 of Appendix C.) Positive percentage error indicates an over-projection. The average absolute percentage errors for each product area for FY81, FY82, FY83, and FY84 were 12.1, 9.8, 10.2, and 11.5 percent, respectively, while total errors for all product areas were 1.7, 2.9, 7.1, and 2.5 percent.

Table 1

Summary of Difference Model Validation Results When Model Coefficients are Re-estimated Without Data for Validation Year

Year	Percentage of Error Summarized by Product Area			Total
	Minimum	Maximum	Average Absolute	
FY81	0	+22.4	12.1	+1.7
FY82	-0.7	+38.0	9.8	+2.9
FY83	+1.2	+24.7	10.2	+7.1
FY84	-0.1	+78.4	11.5	+2.5

Second, the MEM was used to estimate direct workyears from the FY84 Project Listing in-house and contract funding data. The MEM overpredicted total workyears by 10 percent and the average absolute percent error was 17.3 percent.

Finally, the FY84 Project Listing Data, aggregated to the product area level, was used to estimate new model coefficients. The resulting coefficients for the in-house (10.70) and contracting out (0.70) variables were almost identical to the coefficients estimated using the base year planning data.

### Model Operation

The MEM is operational on an IBM XT microcomputer. The user-friendly software, written in BASIC, allows the user to change input parameters, such as total funding, percent in-house funding, and laboratory "direct-to-total" workyear percents, for parametric or "what if" analyses. The user can also input ceilings on total workyears and reallocate workyears and in-house/contractor mixes across product areas.

Figure D-1 in Appendix D presents an operational diagram of the DNL Manpower Planning System with its three major subsystems, Update, Planning, and Allocations. The Update subsystem allows the user to permanently revise the data base used by the model for FY85, FY86, and FY87. Items that can be revised are the consumer price index (CPI) and direct-to-total workyear percents for each R&D center; direct workyears, total funding, and percentage of total funding expended in-house can be revised for each product area.

#### The Planning Subsystem

The Planning Subsystem allows the user to project direct and total workyears based on the R&D center's submitted budget and on user policy inputs (e.g., percentage of in-house funding). The user has the option of exercising the model for an aggregate of all product areas (the global option) or for an individual product area. For either option the user can display historical data for FY80 through FY84, budget projections for FY85 through FY87, and workyear projections for FY85 through FY87. The user can revise percentage of in-house funding, total funding, consumer price index, and laboratory direct-to-total workyear percentages, and can produce several tables and graphs for both the global and product area cases.

Table 2 shows an example of a tabular report for comparing aggregate direct SE&T model and laboratory-submitted workyear projections. Policy input variables (total funding, percent in-house funding, inflation factor, CPI, and direct to total workyears) are also displayed for both historical and projected workyears for each fiscal year. In the graphic form, only the workyears are displayed (see Figure 1).

#### The Allocation Subsystem

The Allocation subsystem assumes fixed funding and externally constrained workyears. This would be the case, for example, if personnel ceilings were imposed. The resulting problem would be to reallocate funding between in-house and contracting out work to conform to in-house workyear constraints.

The user inputs desired total workyears for FY85, FY86, and FY87. The model spreads these values across product areas based on laboratory-submitted workyears for FY85, FY86, and FY87, respectively. The user is then provided the option of readjusting or "fencing" direct workyears for selected product areas. This might be necessary where priorities preclude the option of changing the in-house work effort for specific product areas.

For example, assume that R&D center total workyears for FY85 are reduced 18.3 percent from the budgeted value of 24,466.6 to 20,000. This constrained value can be input and the system will "fair-share" the workyear reduction based on the submitted workyears of each product area. Complete results are displayed in Table D-1 of Appendix D. Both the direct and total workyears in each product area have been reduced so that the aggregate total workyears is 20,000. Revised in-house/contract mixes for each product area are also displayed. Figure 2 shows the laboratory-submitted and revised in-house percentages for five large product areas and for the total.

The user can also "fix" workyears for specific product areas and reallocate the remaining workyears for the other product areas using the fair-share algorithm. Table D-2 of Appendix D shows an example with direct workyears for the Missile product area fixed at 1,500 and aggregate total workyears constrained at 20,000. Direct workyears for any number of product areas can be "fenced" at the same time.

Table 2  
Aggregate Direct SE&T Workyear Projections

	Actual			Laboratory-Submitted			Model				
	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87			
Direct SE&T Workyears	12,002.0	11,962.0	12,444.0	12,543.9	13,507.6	12,637.8	14,113.0	13,995.0	13,954.2	15,399.0	15,276.1
Total Program (\$M)	1,767.3	1,896.2	2,125.9	2,381.7	2,706.2	3,230.2	3,321.0	3,460.0	3,230.2	3,321.0	3,460.0
In-house % total	52.6	54.1	53.3	53.1	53.8	47.8	54.2	53.6	47.8	54.2	53.6
In-house (\$M)	929.6	1,026.0	1,132.9	1,264.3	1,456.1	1,542.6	1,800.6	1,854.0	1,542.6	1,800.6	1,854.0
Contracting-out (\$M)	837.7	870.2	993.0	1,117.4	1,250.1	1,687.6	1,520.4	1,606.0	1,687.6	1,520.4	1,606.0
CPI <sup>d</sup> (1967-100)	246.8	272.4	280.5	289.1	300.7	312.7	325.2	338.2	312.7	325.2	338.2

<sup>d</sup>The consumer price index (CPI) is used to estimate inflation.

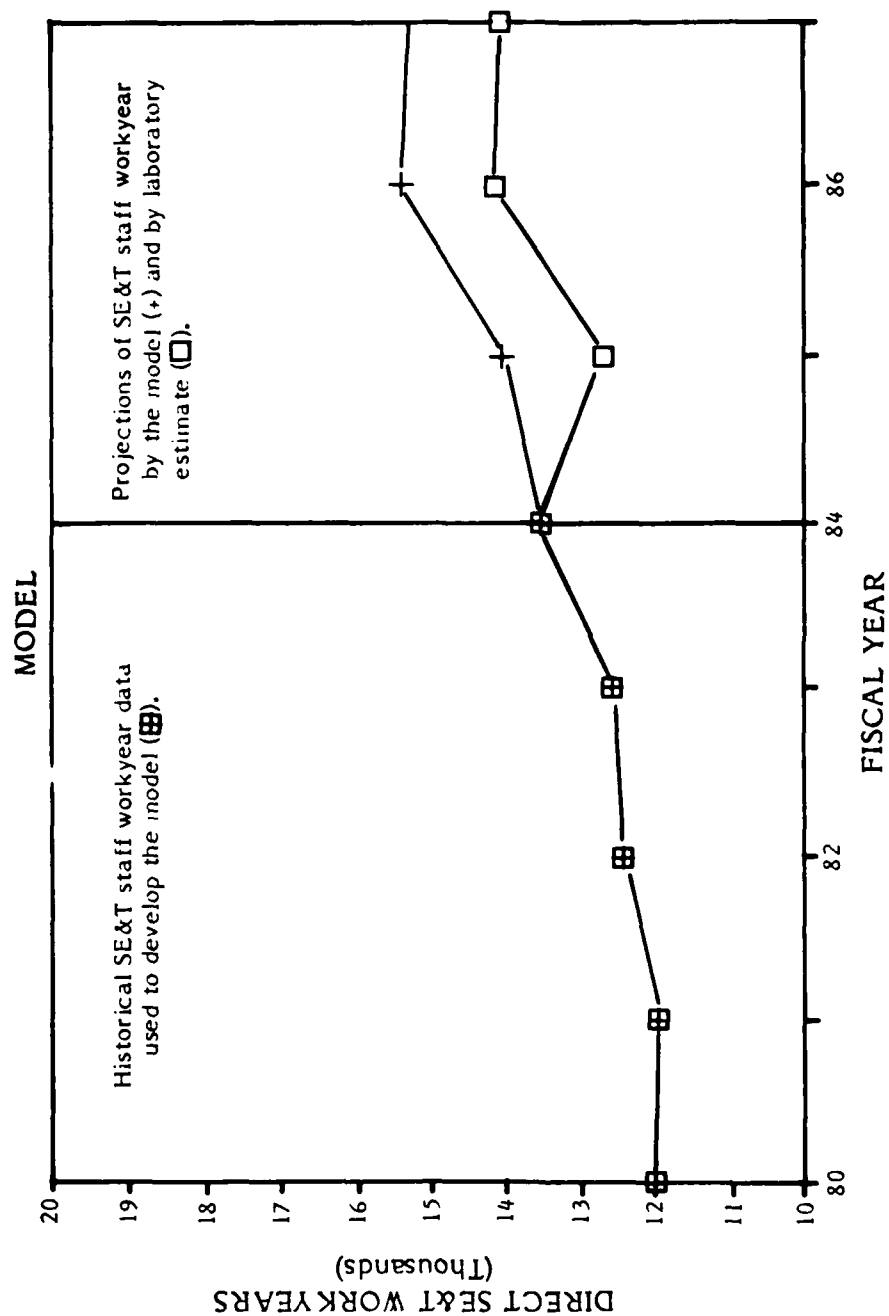


Figure 1. Aggregate workyear comparison.

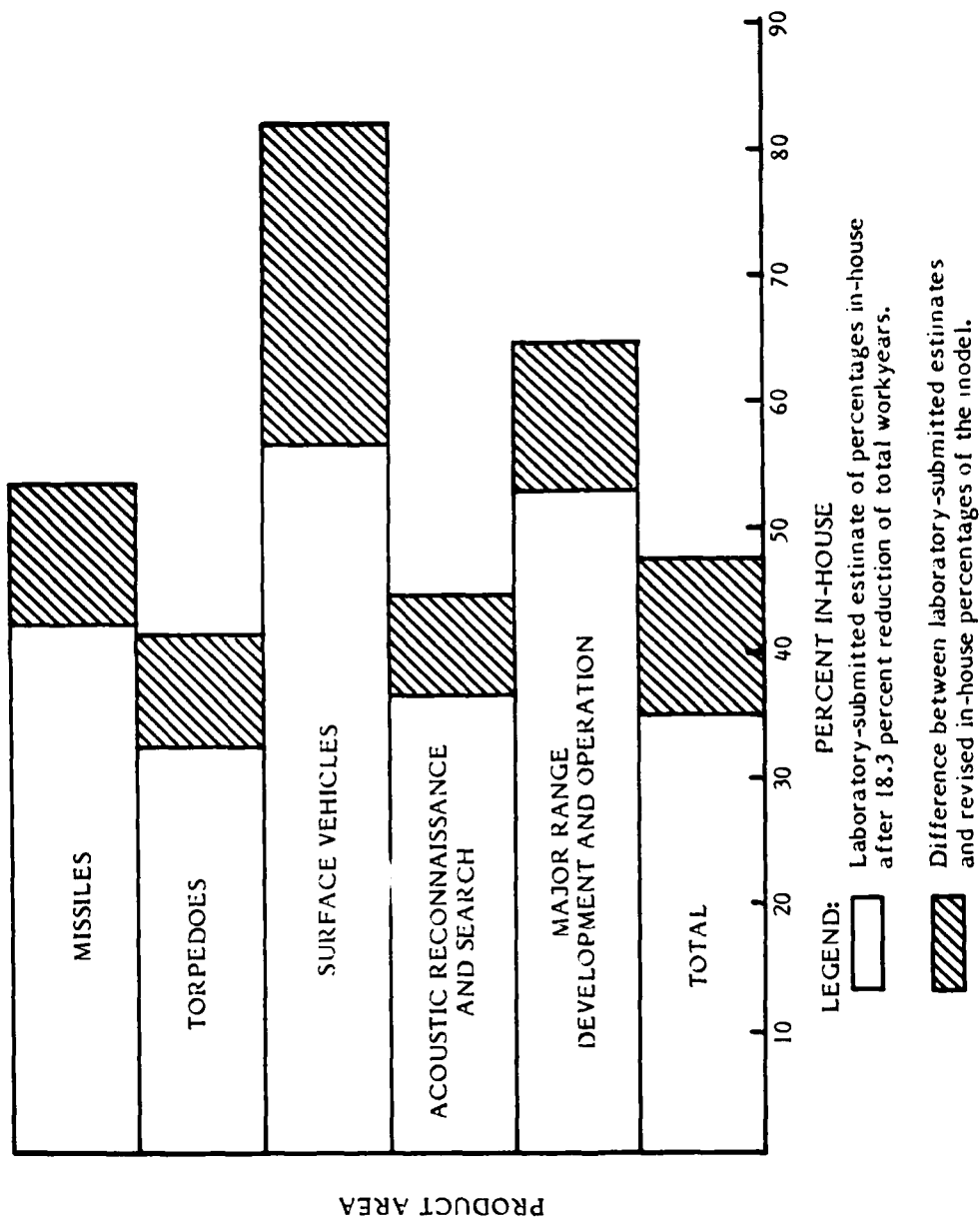


Figure 2. Impact of an 18.3 percent reduction of total workyears on percentage of work done in-house.



The trade-off between direct workyears and percentage of in-house work for each product area can be displayed graphically as shown in Figure 3. The graph can be used to approximate direct workyears if total funding and percent in-house are constrained. The revised direct workyears and percent in-house (point 0) and submitted percent in-house and direct workyears (points + and x) are labeled on the graph. Two points are used for the submitted values because the submitted direct workyears and percent in-house may not equal the model values for unconstrained total workyears and percent in-house.

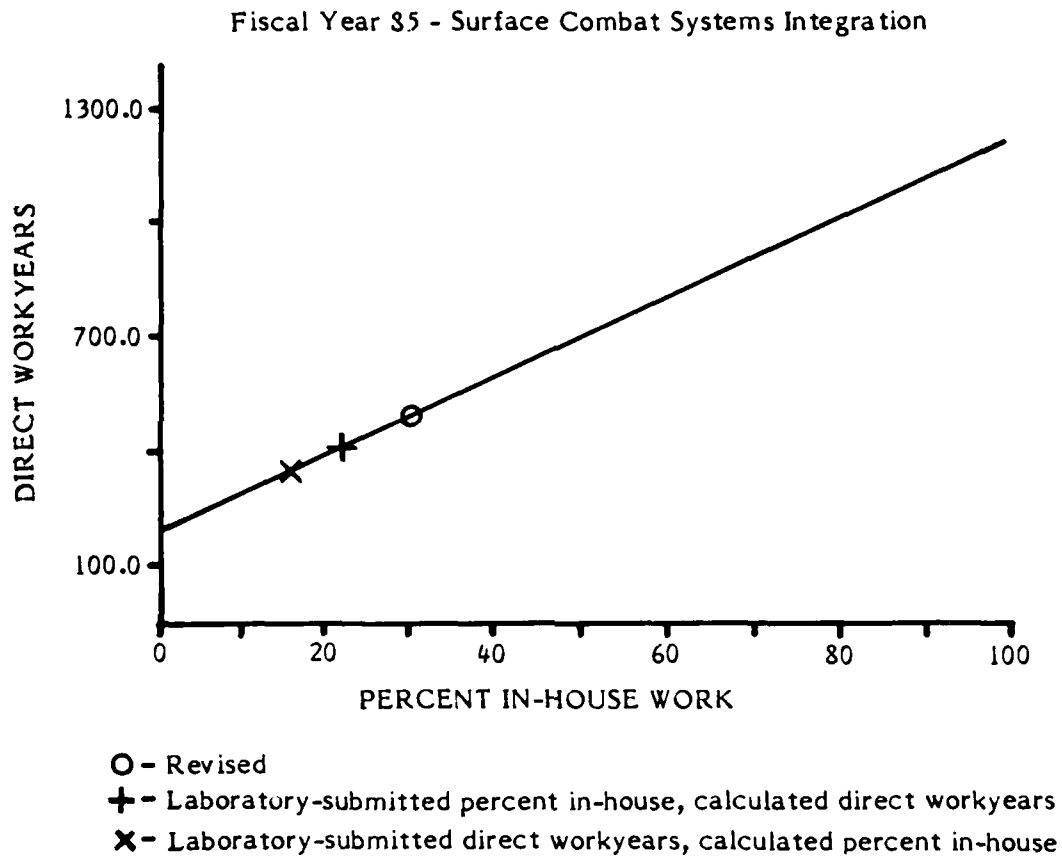


Figure 3. Direct workyear and percent in-house tradeoff.

## CONCLUSIONS AND FUTURE PLANS

The MEM meets the primary objective of matching workload to workforce and forecasting staffing requirements for the eight DNL R&D centers. It satisfies DNL's interim requirement until individual models for each R&D center are developed. Development of individual models for each R&D center will insure that the eight centers will meet the congressional requirement for staffing controls.

DNL financial managers can use the model in the budget justification and review process by changing policy variables and projecting the effects on direct and total workyears by product area. They also can use the system to analyze the impact of personnel ceiling constraints and in-house dollar expenditure limits.

The same approach could be extended to the Naval Research Laboratory and the Naval Ocean Research and Development Activity. This would provide these activities with manpower estimating models and staffing control coverage in the Navy Manpower Engineering Program and give the Office of the Chief of Naval Research a manpower planning system for its two major R&D centers.

**APPENDIX A**

**PREVIOUS ATTEMPTS TO STANDARDIZE AND VALIDATE  
RESEARCH AND DEVELOPMENT MANPOWER REQUIREMENTS**

## **PREVIOUS ATTEMPTS TO STANDARDIZE AND VALIDATE RESEARCH AND DEVELOPMENT MANPOWER REQUIREMENTS**

In 1972, in response to congressional concerns, the Navy started developing a system to determine and justify its total shore-based manpower requirements. This system, called the Shore Requirements, Standards, and Manpower Planning System (SHORSTAMPS), was officially adopted by the Navy in March 1976. SHORSTAMPS emphasized the development and use of staffing standards.

While recognizing that SHORSTAMPS could be used for the overhead functions within research and development (R&D) centers, the Chief of Naval Material (CNM) recommended in November 1975 that research, development, test, and evaluation (RDT&E) work be expected from the SHORSTAMPS program on the basis that any staffing standards would tend to be invalid for RDT&E functions due to the dynamic and uncertain nature of the work. The Chief of Naval Operations (CNO) tentatively agreed with CNM. In June 1976, however, Congress expressed concern over the lack of progress being made and directed that the Navy accelerate the SHORSTAMPS program. Largely as a result of this Congressional pressure, and the relatively large quantity of manpower assigned to RDT&E work (over 30,000), CNO reversed its earlier decision to exempt RDT&E from the SHORSTAMPS program.

In 1977, OPNAV tasked the SHORSTAMPS field office at the Navy Manpower and Material Analysis Center, Pacific (NAVMMACPAC) to develop a methodology to quantify R&D manpower requirements. As a result of their efforts, NAVMMACPAC proposed a modified DELPHI approach called Iterative Polling Technique (IPT). Briefly, the IPT used interviews and questionnaires to form a consensus among experienced Navy R&D performers about the manpower requirements of "typical benchmark" projects in 63 technology areas. The long-term objective was to apply these estimates to similar tasks at the R&D centers.

Because of doubts about the cost effectiveness and validity of the IPT, the Director of Navy Laboratories (DNL) tasked the Navy Personnel Research and Development Center (NAVPERSRANDCEN) to evaluate the IPT and investigate alternative ways of estimating manpower requirements for direct R&D functions. NAVPERSRANDCEN executed this tasking under a contract with SRI International.

In 1979, SRI reported that the IPT was not valid or accurate for estimating Navy R&D manpower requirements and would be very expensive to implement and maintain. SRI recommended adapting the manpower planning method developed by the Navy Civil Engineering Laboratory (NCEL), Port Hueneme. This method was used by NCEL for several years to forecast and justify its manpower requirements. It recognized funding as the "driver" of manpower and used historical data on the pattern of expenditures of incoming funds to support various categories of laboratory manpower in each of the laboratory's technology areas. In 1979, CNO delayed any further development of the IPT and directed the SHORSTAMPS program to concentrate on non-R&D functions.

In 1983, CNO began developing the Navy Manpower Engineering Program (NAVMEP) as a consolidation of SHORSTAMPS, the Commercial Activities Program, and Management Engineering. NAVMEP was approved by the Secretary of the Navy (SECNAV) in December 1983 to provide capability for planning, programming, and budgeting manpower resources. NAVMEP's response to continuing congressional pressure was commitment to total validated staffing controls for the shore establishment in two years.

The NAVMEP approach is a heirarchy of methodologies with efficiency reviews as one of the most preferred, and unvalidated authorizations as the least preferred. One of the preferred methodologies, the manpower estimating model, mathematically relates aggregate measures of workload in specific program areas to manpower requirements.

**APPENDIX B**  
**PRODUCT AREA DEFINITIONS**

## PRODUCT AREA DEFINITIONS

The following product area definitions are from Chief of Naval Material, Long Range Plan for Navy R&D Centers and Laboratories FY-1985 to FY-1989 and Beyond (U), dated October 1984 (pp. B-1 through B-5).

### 10 - Combat System Integration (U)

(U) Combat Systems Integration is defined as that effort required to introduce a new system into the operating forces. It involves the integration and evaluation of a new hardware or software subsystem installed in a Navy platform. It includes the mating, installation and operational support of the resulting higher level system to ensure optimum operating performance.

11. (U) Surface Combat System Integration - The integration and evaluation of the various hardware and software subsystems that make up a high level system, and the mating, installation and operational support of this higher level system, including its operational software and training systems into surface ship platforms.
12. (U) Subsurface Combat System Integration - The integration and evaluation of the various hardware and software subsystems that make up a higher level system, and the mating, installation and operational support of this higher level system, including its operational software and training systems into submarine platforms.
13. (U) Air Combat System Integration - The integration and evaluation of the various hardware and software subsystems that make up a higher level system, and the mating, installation and operational support of this higher level system, including its operational software and training systems into aircraft platforms.
14. (U) Multiplatform Combat System Integration - The integration of multiplatform hardware and software subsystems to make up a higher level system. Includes the mating, installation and operational support (including training systems) of this higher level system.

### 20 - Weaponry (U)

(U) Weaponry is defined as a system that provides the capability to defeat naval and military targets by destructive means. Included are counter-countermeasures and other design features to reduce the susceptibility of the weapon to counter actions, but excluded are those projects in which the principal objective is to counter a weapon system or those efforts to make a system (other than weapons) less vulnerable to enemy weapons.

21. (U) Gun Systems - Ordnance which fires projectiles; includes related ammunition (guided projectiles are included in "Missiles").
22. (U) Missiles - A weapon, either self-propelled (i.e., reaction launched) or impulse driven (i.e., gun/tube impulse launched) capable of homing on, or following a beam or command signals through the air to a target (includes guided projectiles).

23. (U) Free Fall Weapons - Those air-delivered weapons, including components and subsystems, which follow a ballistic trajectory after gravity launch without any guidance other than that from the initial orientation and velocity of the launching aircraft.
24. (U) Torpedoes - Self-propelled, guided or unguided underwater weapons.
25. (U) Mines - Self-activating, standoff or contact explosive devices that are assigned to destroy or damage ground vehicles, boats, ships or aircraft, or designated to wound, kill, or otherwise incapacitate personnel.
26. (U) High Power Radiation - Devices and techniques for generating high intensity beams of electromagnetic energy or charged particles that have lethal effects on targets.
27. (U) Explosives - Metastable compounds which can rapidly release large quantities of energy mostly in the form of hot, high-pressure gases. Explosives are used in naval munitions such as mines, torpedoes, missiles, etc., and also in other Navy products such as aircraft escape systems, fuse trains, etc.
28. (U) Launchers - That group of devices, components, or subsystems needed to support, hold, and launch expendable weapons, countermeasure devices, or other stores; the control systems for managing these systems and the stores they carry.
29. (U) Fire Control - Those platform-based systems which provide data for and/or control the launch platform/weapon/weapon-target interaction in all phases required by a weapons system (e.g., acquisition, track, commit-to-fire, pre-launch, post launch, mid-course, terminal intercept, and assessment).

### 30 - Countermeasures (U)

- (U) Countermeasures are defined as those systems that are principally designed to defeat a particular weapon system; those systems that are designed to reduce the effectiveness of an enemy's surveillance, communications, navigation and command and control; as well as those efforts directed toward gathering information on the emissions of enemy systems. It does not include those projects in which the principal objective is to incorporate design features in vehicles, surveillance, communication, navigation and other support systems which reduce their vulnerability to enemy action.
30. (U) Electronic Warfare Systems - Those systems, techniques and devices utilized to determine, exploit, reduce or prevent hostile use of the electromagnetic spectrum.
  32. (U) Underseas Countermeasures - The technology base, components, systems and techniques to: (a) conventionally or remotely sweep, detect, classify, neutralize, and/or avoid present and projected sea and/or surf zone mines; (b) detect, localize, classify, jam, deceive, decoy and neutralize torpedoes and subsurface missiles as well as acoustic sensors from surface and submarine platforms; and (c) develop tri-service explosive ordnance disposal equipment and techniques.



#### 40 - Special Operational Support (U)

(U) Special Operational Support is defined as those special development efforts which are in support of amphibious landings, Marine Corps operations, special warfare and such other unique operations as may be designated. It includes weapons, countermeasures, vehicles, surveillance and command support which are developed specifically for the projection of forces ashore and that do not have an application by the Navy general forces in the major role of sea control.

41. (U) Landing Force Equipment and Systems - Involved is that RDT&E effort which is not functionally a part of the amphibious platform. Specifically, it includes reconnaissance of amphibious objective areas, environmental support of amphibious operations, amphibious logistics and the integration of the amphibious and Marine Corps systems required to land amphibious forces on a hostile shore and establish a beachhead. (Contingency facilities in support of forces ashore are included in 82, "Facilities".) This latter role includes functional interface of equipment, supplies and personnel, central ship-to-shore movement and logistic support, as well as countermeasures for land mines and booby traps.
42. (U) Coastal/Special Warfare Support - Techniques and systems required to defend coastal, inshore and harbor facilities as well as those needed to conduct operations such as reconnaissance, deception, coastal or offshore interdiction and assault, counterinsurgency, intelligence gathering, remote sensor operation and waterborne intrusion detection. Special warfare systems include systems, techniques, and concepts utilized by specifically cross-trained personnel in unconventional warfare and coastal/riverine operations.

#### 50 - Vehicles (U)

(U) Vehicles are defined as those self-propelled, boosted or towed conveyances used for the strategic and tactical deployment of forces, weapons, materials and supplies in support of naval warfare. Projects within this area are limited to those in which the principal objective is to provide technological wherewithal to develop Navy aerospacecraft, ships, submarines, boats and amphibians.

51. (U) Surface Vehicles - A self-propelled or towed conveyance for transporting a burden on land or sea. The Vehicle's package includes the design, structures, materials, non-nuclear propulsion, power and auxiliary equipment, transmissions and propulsors, fuels and lubricants, energy conservation and pollution abatement equipment, control systems, and silencing inherent in its construction and operation, but excludes mission-oriented systems. Included are ships and craft including their application as Remotely Piloted Vehicles (RPVs) and Targets.
52. (U) Subsurface Vehicles - A self-propelled, boosted, or towed conveyance for transporting a burden under the sea. The Vehicle's package includes the design, structures, materials, non-nuclear propulsion, power and auxiliary equipment, transmissions and propulsors, fuels and lubricants, energy conservation and pollution abatement equipment, control systems, and silencing inherent in its construction and operation, but excludes the mission-oriented systems. Included are submarines and other submersibles including their application as RPVs and Targets.

53. (U) Naval Air Vehicles - A self-propelled, boosted, or towed conveyance for transporting a burden through the air. The Vehicle's package includes the design, structures, materials, non-nuclear propulsion, power and auxiliary equipment, transmissions and propulsors, fuels and control systems and silencing inherent in its construction and operation, but excludes mission-oriented systems. Included are all air vehicles including their application as RPVs and Targets.
54. (U) Crew Equipment and Life Support - Equipment and devices to provide protection for and support of naval operating personnel, including chemical/biological defense.

#### 60 - Surveillance (U)

(U) Surveillance systems are defined as those systems used to systematically observe air, space, surface and subsurface areas to detect, classify, localize and identify real or potential military targets. Excluded are those projects in which the principal objective is navigation, weapon fire control or broad-based investigation of the properties of the media or the propagation of energy therein.

61. (U) Acoustic Reconnaissance and Search - Those systems and devices which utilize acoustic phenomena to conduct search; reconnaissance; and search to detect, classify, locate, and/or track targets.
62. (U) Electromagnetic Reconnaissance and Search - Those systems and devices which utilize electromagnetic phenomena to conduct search; reconnaissance; and search to detect, classify, locate, and/or track targets.
63. (U) Special Sensors - Those systems and devices which utilize unique phenomena, methods, or combinations of methods to conduct search; reconnaissance; or surveillance operations to detect, classify, locate, and/or track targets.
64. (U) Ocean Surveillance - Systems and equipment for systematic observation of ocean areas for identification and localization of ships, submarines, and aircraft from fixed and mobile platforms including operational software development, and integration of multisensor, coordinated detection data and its display at appropriate sites.

#### 70 - Command Support (U)

(U) Command Support is defined as the acquisition, processing and dissemination of information required by a Commander in planning, directing and controlling operations. Included are those projects in command and control, communications and navigation. Excluded are surveillance systems, guidance and control of vehicles and weapons; as well as the management or distribution of personnel, material and facilities by rear echelon support headquarters.

71. (U) Command and Control - The facilities and equipment, and procedures used for planning, directing, and controlling naval forces and operations.
72. (U) Communications - Systems and equipment for conveying information of any kind from one person, place or equipment to others.

73. (U) Navigation - Those systems which utilize electromagnetic, acoustic, or inertial means to guide or navigate surface, subsurface, or aerospace platforms.

80 - General Mission Support (U)

- (U) General Mission Support is defined as those major areas of support required by Navy general forces in the major role of sea control that are not included under weapons, countermeasures, vehicles, surveillance, command support or special interest. It does not include the special efforts in support of amphibious landing, Marine Corps operations and special warfare support.
81. (U) Logistics - Includes RDT&E for those aspects of military operations which deal with the movement, maintenance, supply and support of naval forces afloat and ashore, including underway replenishment, warehousing and mobile logistics maintenance and repair activities; material acquisition, control, handling, distribution and disposal processes; and logistics planning, control, and information processing functions.
82. (U) Facilities - Products for (a) ocean facilities including the siting, design, construction/implant, and maintenance of facilities attached to the seafloor such as cable structures, pipelines, communications/power cables and Fleet moorings; (b) contingency facilities and equipment to support Navy and Marine Corps forces ashore in amphibious objective areas and at advanced naval bases; (c) permanent shore facilities such as buildings, piers, drydocks, airfields, POL and weapons storage, and utilities; (d) energy systems ashore including conservation, synthetic fuels, energy self-sufficiency; and (e) environmental protection systems ashore such as industrial wastewater treatment plants, air and noise pollution control devices, and solid waste management systems.
83. (U) Personnel and Training - Human resources and development for the areas of manpower, personnel, education, and training and its support and service functions for human factors effects in system design, development and acquisition.
84. (U) Diving, Salvage and Ocean Engineering - Those support systems and equipment that are required by the Navy in the performance of ocean bottom search, diving, rescue, recovery, and salvage operations; and siting, design, construction/implantment, inspection, maintenance and recovery of underwater structures and associated systems.
85. (U) Environmental Description, and Effects Prediction - The measurement, modeling, analysis, and prediction of changes in the natural atmosphere and ocean environments caused by radiation, wind, tides, temperature, organic and inorganic matter from natural or man-made phenomena, and their effects on naval systems and operations.

#### 90 - Special Interest (U)

(U) *Special Interest* programs are defined as those programs that are so unique that they do not fit in an organized structure, that are singled out at the prerogative of higher management, or that are the result of newly emerging technology. Programs that are specifically directed toward improving the Navy in-house RDT&E capability are included in this area.

91. (U) Navy Strategic systems - Those ships and weapons systems, subsystems, devices, techniques, trainers and facilities required specifically for the deployment and use of the Navy's strategic deterrence force.
92. (U) Space Systems and Technology - The conception, development and utilization of systems, components, and techniques for space applications in navigation and in the acquisition and transmission of information.
93. (U) Major Range Development and Operation - Design, equip, and operate ranges offering diverse and accurate measurement and reconstruction capabilities to establish performance profile data on newly designed, as well as existing naval vehicles and systems operating in an realistic environment.
94. (U) Nuclear Weapons and Effects - Tactical nuclear weapons, nuclear weapons effects and countermeasures, including thermal and nuclear radiation effects and the hardening of components and weapons systems, both nuclear and non-nuclear.
95. (U) Center (Laboratory or Activity) Missions and Function Support - Efforts that clearly support the Center's product responsibilities but which cannot be uniquely assigned to a specific product area.

**APPENDIX C**

**DETAILED RESULTS OF MODEL DEVELOPMENT AND VALIDATION**

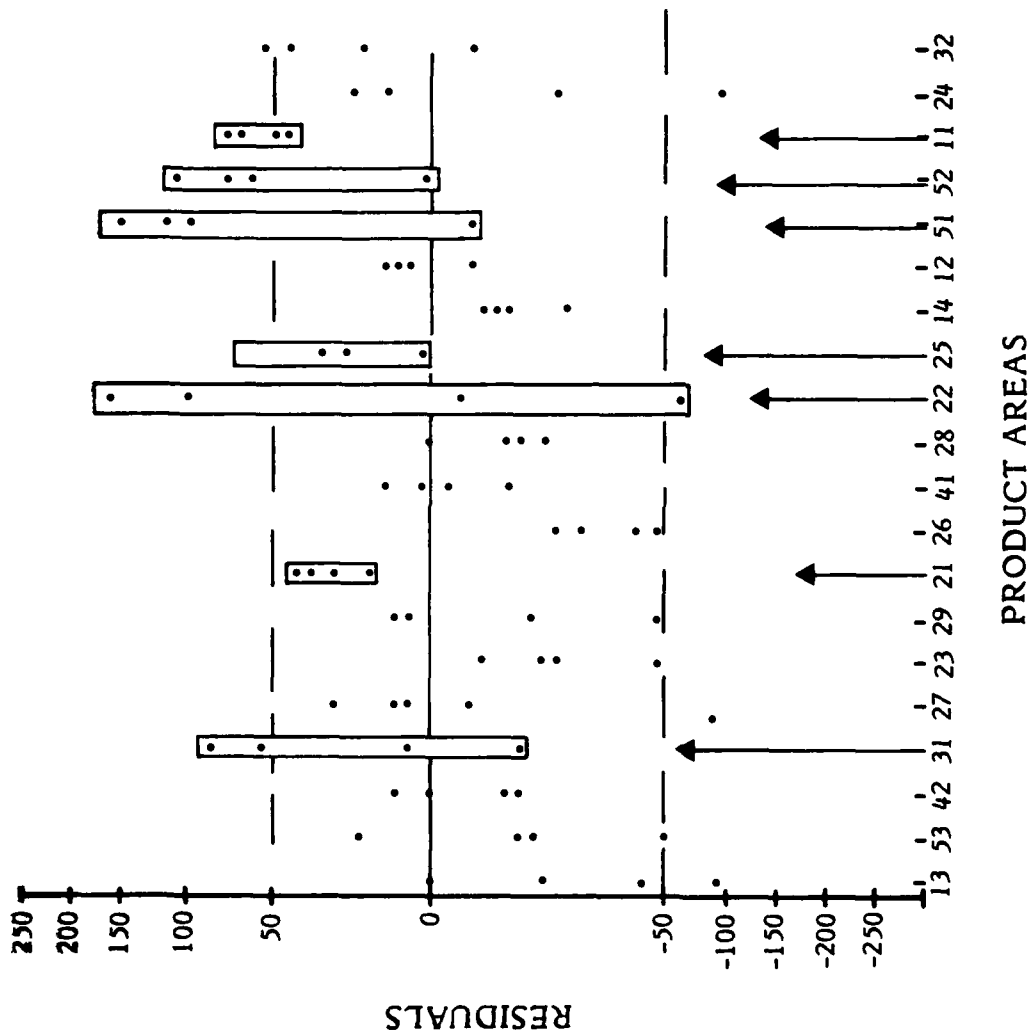


Figure C-1. Plot of residuals by product area. (Residuals are calculated as the difference between actual and estimated workyears. See Appendix A for definitions of product areas corresponding to the numbers.)

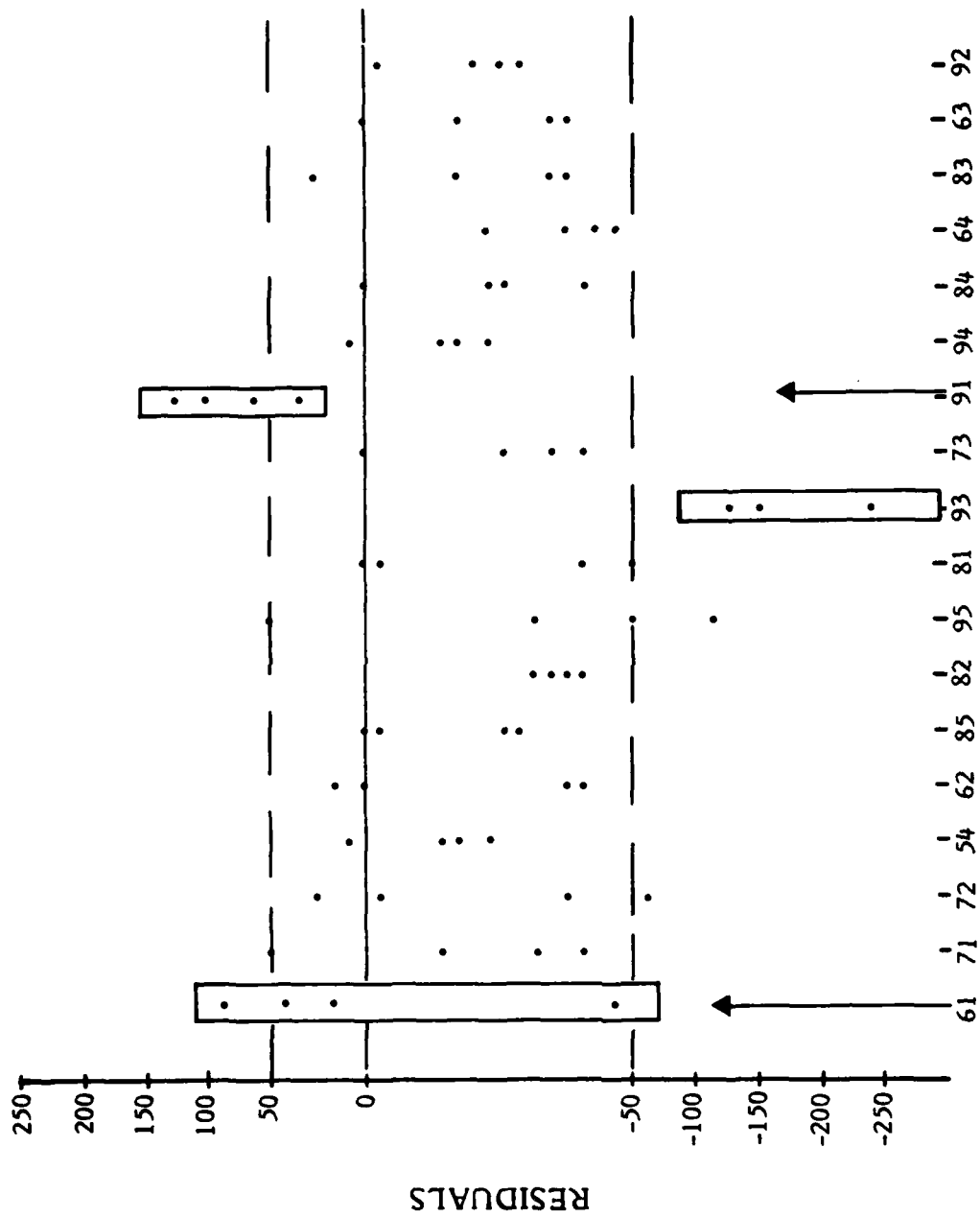


Figure C-1. (Continued).

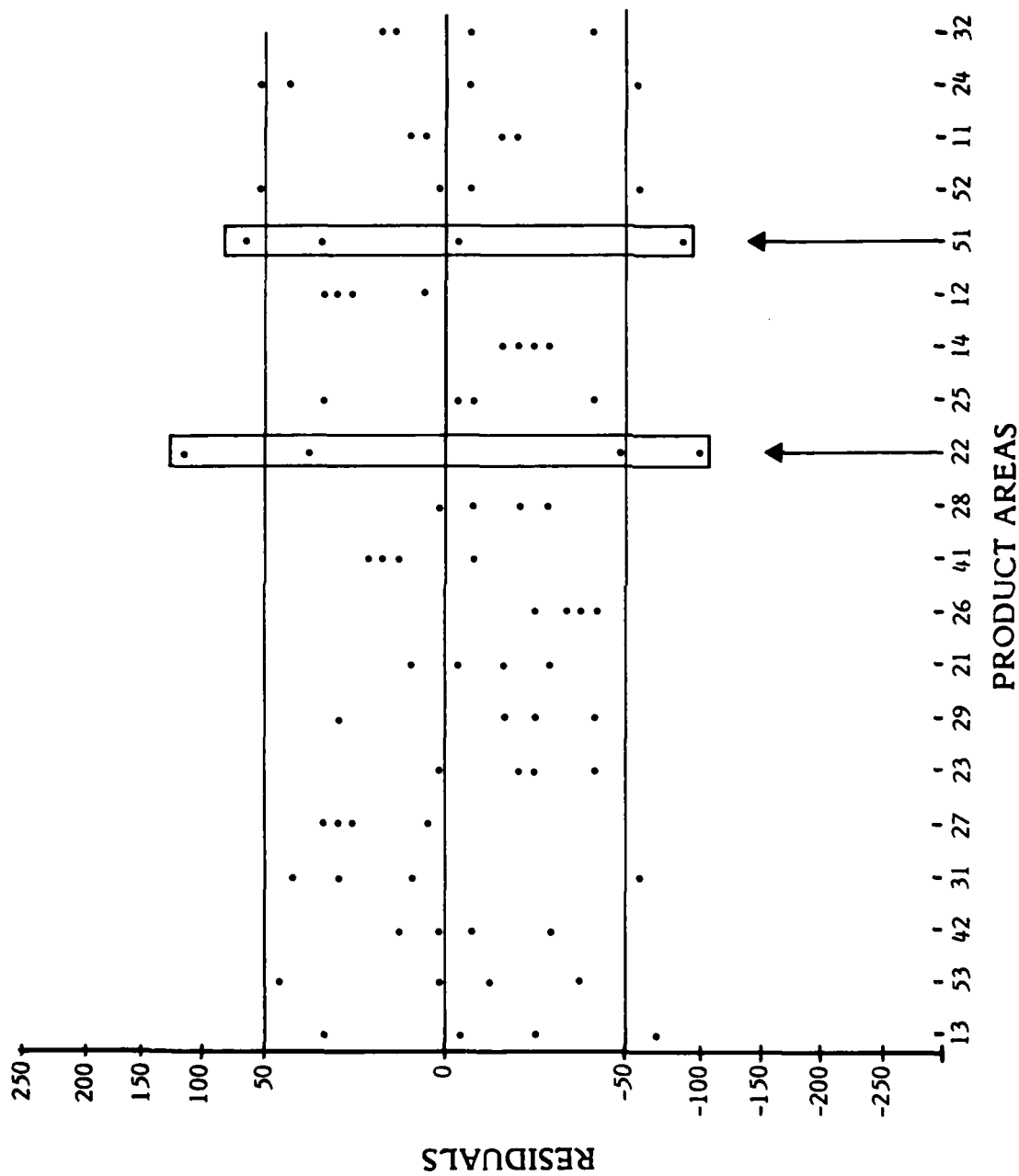


Figure C-2. Plot of residuals by product-area with dummy intercept variables. (See Appendix A for definitions of product areas corresponding to the numbers.)



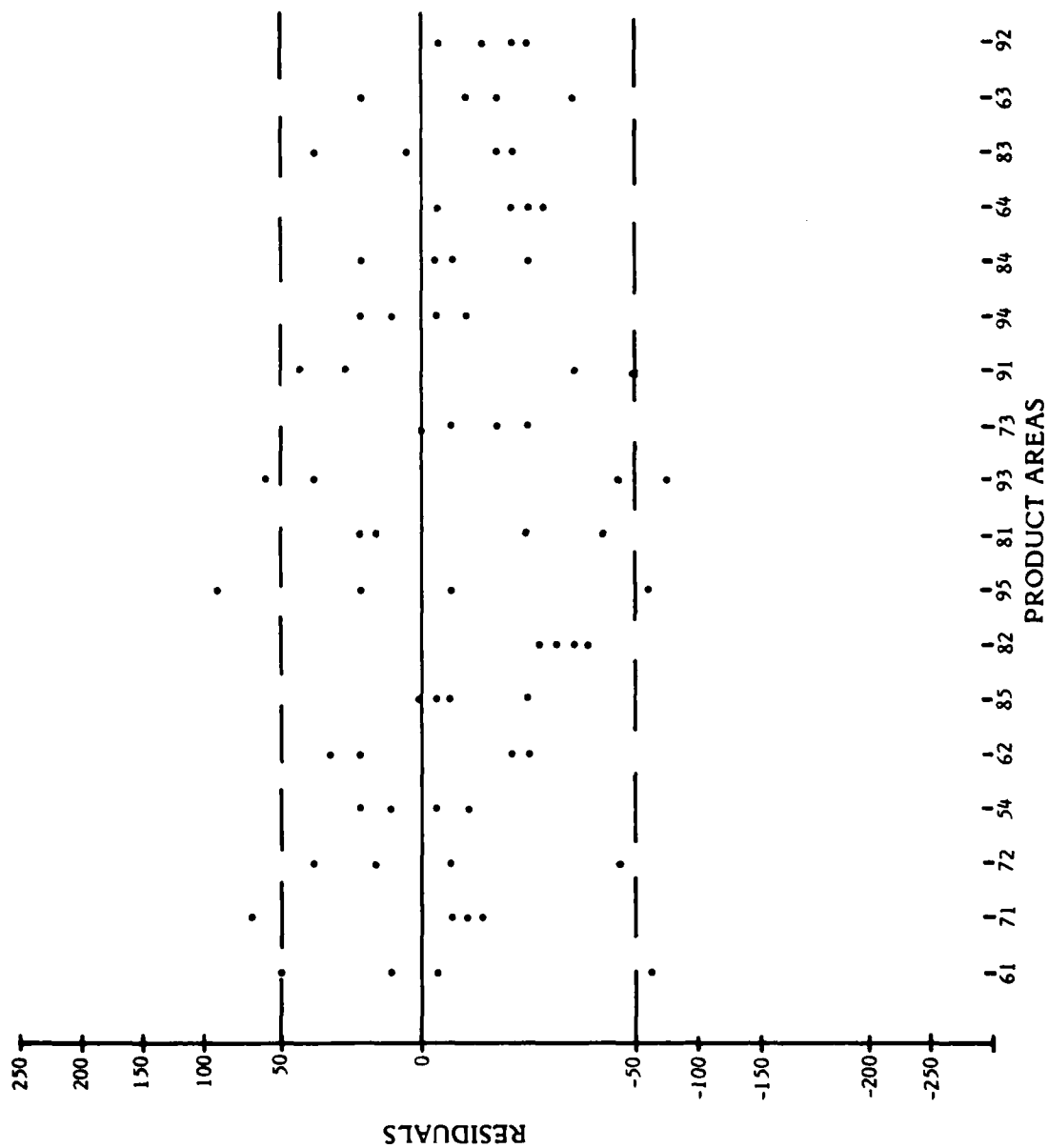


Figure C-2. (Continued).

Table C-1

## Comparison of Ordinary Least Squares and Difference Equations

PRODUCT NUMBER	PRODUCT AREA	FY84 ACTUAL WYRS	OLS MODEL % DIFF	DIF MODEL % DIFF
11	SUR CBT SYS IN	538.0	-3.6	-0.8
12	SBS CBT SYS IN	172.8	-2.8	3.5
13	AIR CBT SYS IN	513.8	22.2	10.5
14	MTP CBT SYS IN	38.9	48.0	-3.9
21	GUN SYSTEMS	211.3	-14.2	0.3
22	MISSILES	1531.3	4.2	-0.7
23	FREE FALL WPNS	117.2	12.5	-14.7
24	TORPEDOES	718.0	3.4	-4.4
25	MINES	281.8	-10.0	-3.8
26	HI PWR RAD DV	50.9	69.7	6.9
27	EXPLOSIVES	144.4	-1.4	4.3
28	LAUNCHERS	121.9	16.8	7.6
29	FIRE CONTROL	494.1	-2.4	-5.7
31	EW SYSTEMS	512.4	-5.9	-5.6
32	UNDERSEAS CMS	330.6	0.1	5.6
41	LF EQUIP SYS	135.3	0.2	15.7
42	CBT L/SPEC WFR	97.6	8.0	-3.6
51	SUP VEHICLES	663.1	16.4	8.2
52	SURF VEHICLES	798.4	9.1	6.1
53	AIR VEHICLES	479.0	-1.0	-0.9
54	CREW EQUIP/LS	190.6	-6.5	-6.6
61	ACQU RECN/SRCH	679.9	0.5	-0.2
62	EM RECN/SRCH	252.3	15.2	11.3
63	SPEC SENSORS	133.8	17.8	17.9
64	OCEAN SURVLNCE	241.0	17.5	8.6
71	COM & CTRL	265.9	20.0	17.1
72	COMMUNICATION	464.9	6.9	-1.4
73	NAVIGATION	204.7	9.8	-0.9
81	LOGISTICS	169.6	19.7	11.4
82	FACILITIES	21.1	114.2	9.0
83	PERSNL/TRAING	221.1	-1.8	4.3
84	OCEAN ENGRING	104.3	29.9	11.7
85	ENVIRONMENT	132.1	14.7	8.0
91	NAVY STRAT SYS	478.3	20.2	16.1
92	SPACE SYS/TECH	71.0	14.6	-9.3
93	MAJ RNGE DV/DP	637.1	11.6	9.0
94	NUCLEAR WP/EFF	129.0	-5.6	-3.1
95	GEN MISSION FS	1160.1	3.1	-2.6
TOTAL		13507.6	6.4	2.4

Table C-2

Difference Model Validation Results when Model Coefficients  
are Re-estimated Without Data for Validation Year

PRODUCT NUMBER	PRODUCT AREA	AVE WYRS	PERCENT ERROR			
			FY81	FY82	FY83	FY84
11	SUR CBT SYS IN	415	1.14	-7.12	1.15	-0.81
12	SBS CBT SYS IN	240	-0.98	1.40	1.34	3.98
13	AIR CBT SYS IN	461	6.15	3.40	11.11	10.73
14	MTP CBT SYS IN	43	-2.17	5.66	19.37	-1.45
21	GUN SYSTEMS	219	-2.61	-4.71	7.18	0.46
22	MISSILES	1351	5.72	8.11	3.88	-0.64
23	FREE FALL WFS	109	12.71	6.34	9.10	-14.49
24	TORPEDOES	609	-1.19	9.62	9.29	-4.41
25	MINES	297	9.64	-3.51	10.87	-3.51
26	HIPWR BAD DV	46	-7.35	-15.24	24.70	8.73
27	EXPLOSIVES	153	0.50	4.06	5.97	4.56
28	LAUNCHERS	120	20.11	-14.68	5.09	8.42
29	FIRE CONTROL	316	-13.34	1.51	18.18	-5.65
31	EW SYSTEMS	433	2.77	11.33	8.19	-5.55
32	UNDERSEAS CMS	324	-0.73	5.82	6.49	5.77
41	LF EQUIP SYS	118	3.52	12.56	-22.30	-16.01
42	CST L/SPEC WFR	87	-9.62	32.27	8.96	-2.99
51	SUR VEHICLES	686	3.31	-7.31	21.96	8.25
52	SSUR VEHICLES	721	-6.32	6.81	7.84	6.18
53	AIR VEHICLES	437	7.45	-14.88	9.97	-0.88
54	CREW EQUIP/L	175	9.88	-6.86	5.74	-6.26
61	ADDU RECN/SRCH	721	6.96	-0.67	8.66	-0.05
62	EM RECN/SRCH	258	-9.14	19.57	-2.30	11.38
63	SPEC SENSORS	124	19.25	6.84	-20.18	18.59
64	OCEAN SURVLNCE	215	-12.64	5.06	5.44	8.65
71	CON & CTRL	389	-21.16	21.51	6.66	17.54
72	COMMUNICATION	421	6.21	6.25	7.50	-1.22
73	NAVIGATION	196	12.91	-10.46	13.30	-20.78
81	LOGISTICS	152	-2.69	38.00	-13.95	-41.34
82	FACILITIES	24	-11.36	7.02	-24.12	9.55
83	PERSONL/TRAING	207	0.00	0.87	-10.76	4.32
84	OCEAN ENGRING	122	7.24	4.45	6.78	11.98
85	ENVIRONMENT	112	-3.12	5.53	6.16	78.40
91	NAVY STRAT SYS	519	-4.64	15.01	3.74	70.82
92	SPACE SYS/TECH	66	-10.32	10.50	12.47	-9.35
93	MAJ RNGE DV/OP	607	21.41	-21.37	17.07	9.04
94	NUCLEAR WFEFF	101	21.53	-8.71	3.88	-3.11
95	GEN MISSION FS	1155	-7.54	8.55	5.41	-2.54
TOTAL		12644	1.74	2.90	2.08	2.54

**APPENDIX D**

**OPERATIONAL SYSTEM DIAGRAM AND SAMPLE  
OUTPUT FROM ALLOCATION SUBSYSTEM**

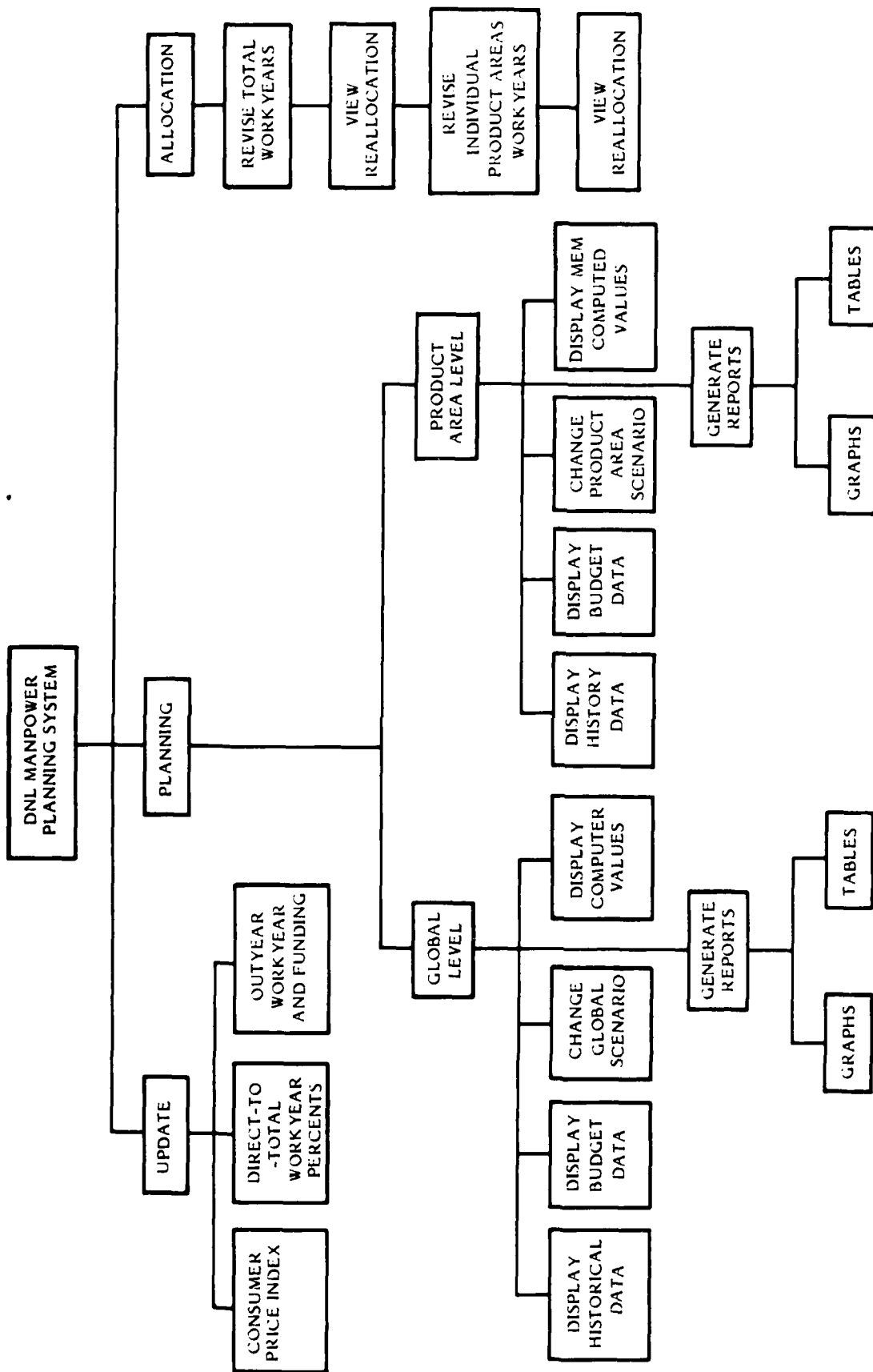


Figure D-1. Operational diagram of DNL manpower planning system.

Table D-1  
Constrained Workyears Scenario

Product Area	Total Workyears		Direct Workyears		% In-house	
	Submit.	Revised	Submit.	Revised	Submit.	Revised
11 SUR CBT SYS IN	565.7	462.4	347.5	284.1	21.5	9.4
12 SBS CBT SYS IN	227.1	185.7	136.5	111.6	57.2	41.8
13 AIR CBT SYS IN	1017.2	831.5	574.6	469.7	46.0	45.0
14 MTP CBT SYS IN	59.6	48.7	36.0	29.4	44.4	40.1
21 Gun Systems	347.5	284.1	210.7	172.2	31.9	21.2
22 Missiles	3108.4	2540.9	1617.3	1322.0	52.9	41.9
23 Free Fall Wpns	191.2	156.3	99.1	81.0	60.4	35.7
24 Torpedoes	1135.9	928.6	678.5	554.6	40.9	32.3
25 Mines	378.5	309.4	232.0	189.6	60.6	47.8
26 High Pwr Rad Dv	127.7	104.4	75.7	61.9	17.2	14.0
27 Explosives	333.2	272.3	194.0	158.6	70.9	53.9
28 Launchers	289.6	236.7	175.1	143.1	35.4	34.9
29 Fire Control	736.6	602.2	435.5	356.0	37.5	30.0
31 EW Systems	832.6	680.6	469.1	383.5	30.2	18.5
32 Underseas CMS	734.6	600.5	445.0	363.8	56.2	38.9
41 LF Equip Sys	156.3	127.7	91.6	74.9	37.5	18.6
42 Cstl/Spec Wfr	164.8	134.7	101.0	82.6	61.8	39.7
51 Surf Vehicles	1430.6	1169.4	842.2	688.4	81.5	56.1
52 Ssurf Vehicles	1014.4	829.2	597.4	488.3	75.7	39.8
53 Air Vehicles	742.8	607.2	433.3	354.2	46.8	33.0
54 Crew Equip/LS	375.2	306.7	223.9	183.0	48.7	35.0
61 Acou Recn/Srch	1103.5	902.0	666.4	544.7	44.3	36.6
62 EM Recn/Srch	537.9	439.7	320.7	262.2	46.7	45.4
63 Spec Sensors	237.0	193.7	139.5	114.0	29.9	19.2
64 Ocean SurvInce	285.2	233.1	164.1	134.1	43.4	37.6
71 Com and Ctrl	643.2	525.8	374.3	306.0	31.9	22.9
72 Communication	958.8	783.8	561.4	458.9	40.3	26.1
73 Navigation	418.2	341.8	253.5	207.2	36.1	29.5
81 Logistics	317.1	259.2	189.9	155.2	58.8	32.7
82 Facilities	41.2	33.7	22.2	18.1	63.3	54.3
83 Persnl/Traing	393.3	321.5	207.2	169.4	51.4	38.8
84 Ocean Engring	177.8	145.3	103.1	84.3	49.1	44.0
85 Environment	246.6	201.6	146.3	119.6	63.7	47.1
91 Navy Strat Sys	684.1	559.2	413.7	338.2	35.9	32.7
92 Space Sys/Tech	75.2	61.4	46.3	37.8	56.7	44.5
93 Maj Rnge Dv/Op	1050.6	858.8	533.6	436.2	64.4	52.7
94 Nuclear Wp/Eff	119.5	97.7	73.0	59.7	67.5	38.7
95 Gen Mission Fs	3207.7	2622.1	1817.8	1485.9	54.5	37.8
Total	24466.6	20000.0	14049.0	11484.2	47.7	35.0

Table D-2

## Effect of Constrained Workyears with Missiles Program Constant

Product Area	Total Workyears		Direct Workyears		% In-house		
	Submit.	Revised	Submit.	Revised	Submit.	Revised	
11	SUR CBT SYS IN	565.7	453.4	347.5	278.5	21.5	8.9
12	SBS CBT SYS IN	227.1	182.0	136.5	109.4	57.2	40.6
13	Air CBT SYS IN	1017.2	815.2	574.6	460.5	46.0	44.2
14	MTP CBT SYS IN	59.6	47.8	36.0	28.9	44.4	39.0
21	Gun Systems	347.5	278.5	210.7	168.9	31.9	20.4
22	Missiles	3108.4	2883.0	1617.3	1500.0	52.9	48.7
23	Free Fall Wpns	191.2	153.3	99.1	79.4	60.4	34.8
24	Torpedoes	1135.9	910.4	678.5	543.8	40.9	31.5
25	Mines	378.5	303.3	232.0	185.9	60.6	46.4
26	Hgh Pwr Rad Dv	127.7	102.3	75.7	60.7	17.2	13.7
27	Explosives	333.2	267.0	194.0	155.5	70.9	52.5
28	Launchers	289.6	232.1	175.1	140.3	35.4	34.1
29	Fire Control	736.6	590.4	435.5	349.0	37.5	29.2
31	EW Systems	832.6	667.3	469.1	375.9	30.2	17.9
32	Underseas CMS	734.6	588.7	445.0	356.6	56.2	37.9
41	LF Equip Sys	156.3	125.2	91.6	73.4	37.5	17.9
42	Cstl/Spec Wfr	164.8	132.1	101.0	80.9	61.8	38.6
51	Surf Vehicles	1430.6	1146.5	842.2	675.0	81.5	54.9
52	Ssurf Vehicles	1014.4	813.0	597.4	478.8	75.7	38.9
53	Air Vehicles	742.8	595.3	433.3	347.3	46.8	32.1
54	Crew Equip/Ls	375.2	300.7	223.9	179.4	48.7	34.0
61	Acou Recn/Srch	1103.5	884.4	666.4	534.1	44.3	35.8
62	EM Recn/Srch	537.9	431.1	320.7	257.0	46.7	44.5
63	Spec Sensors	237.0	189.9	139.5	111.8	29.9	18.7
64	Ocean Survlance	285.2	228.6	164.1	131.5	43.4	36.8
71	Com and Ctrl	643.2	515.5	374.3	300.0	31.9	22.4
72	Communication	958.8	768.4	561.4	449.9	40.3	25.4
73	Navigation	418.2	335.1	253.5	203.2	36.1	28.7
81	Logistics	317.1	254.2	189.9	152.2	58.8	32.0
82	Facilities	41.2	33.1	22.2	17.8	63.3	53.3
83	Persnl/Traing	393.3	315.2	207.2	166.1	51.4	37.7
84	Ocean Engring	177.8	142.5	103.1	82.6	49.1	43.1
85	Environment	246.6	197.7	146.3	117.2	63.7	46.0
91	Navy Strat Sys	684.1	548.3	413.7	331.6	35.9	31.9
92	Space Sys/Tech	75.2	60.2	46.3	37.1	56.7	43.0
93	Maj Rnge Dv/Op	1050.6	842.0	533.6	427.6	64.4	52.0
94	Nuclear Wp/Eff	119.5	95.8	73.0	58.5	67.5	36.9
95	Gen Mission Fs	3207.7	2570.7	1817.8	1456.8	54.5	36.9
	Total	24466.6	20000.0	14049.0	11463.1	47.7	34.9

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